OUTCOME OF ILIZAROV FIXATOR IN INFECTED NONUNION TIBIA

A dissertation submitted to the Tamil Nadu Dr.M.G.R.

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the award of M.S. Branch II (Orthopaedic Surgery) degree

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CERTIFICATE

This is to certify that this dissertation titled **"OUTCOME OF ILIZAROV FIXATOR IN INFECTED NONUNION TIBIA "** is a bonafide work done by **Dr. SHYAMASUNDAR. L.G ,** in the Department of Orthopaedic Surgery, Christian Medical College and Hospital, Vellore in partial fulfillment of the rules and regulations of the Tamil Nadu Dr. M.G.R. Medical University for the award of M.S. Degree (Branch-II) Orthopaedic Surgery under the supervision and guidance of **Prof. Vernon N. Lee** during the period of his post-graduate study from March 2007 to February 2009.

This consolidated report presented herein is based on bonafide cases, studied by the candidate himself.

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AIMS AND OBJECTIVES

- To study patients with infected nonunion of the tibia who were treated with the Ilizarov fixator.

- To study the outcome of infected nonunion of tibia treated with Ilizarov ring fixator .

- To study factors affecting the outcome.

LITERATURE REVIEW

INTRODUCTION-

The ununited tibial fracture compromised by infection is a difficult reconstructive problem for the surgeon and also becomes a chronic illness for the patient. More often the patient has endured multiple hospitalizations, many operative procedures and prolonged treatment with parenteral antibiotics. Infected nonunion of tibia is not only a source of functional disability but also can lead to economic hardship and loss of self-esteem. Despite improvements in managing this condition, the prevalence of infected nonunion of the tibia still remains high. This is due in part to the fact that open tibial fractures frequently result from high velocity injuries, deteriorating road conditions, increasingly sophisticated techniques in the emergency salvage of complex limb injuries, and a continued enthusiasm for operative fracture surgery. In a study done by community health department, Jawaharlal Institute of Postgraduate Medical Education and Research (JIPMER) ,Tamilnadu revealed the highest number of road traffic accidents (RTA) victims (31%) were found between the age group of 20 and 29 years. The similar findings were also reported from Delhi and Nepal also. This shows that the people of the most active and productive age group are involved in RTAs, which adds a serious economic loss to the community.

DEFINITION

Brinker[1] defined nonunion as a fracture that according to treating doctor , has no possibility of healing without surgical intervention.

The Food and drug administration definition for nonunion – The fracture that is over 9months old and that has not shown radiographic signs of progression toward healing for 3 consecutive months.

Out of several parameters that help to identify infected nonunion of a tibial fracture as cited by Toh and Jupiter, exposed bone that has been devoid of vascularized periosteal coverage for more than six weeks and purulent drainage were considered to make a diagnosis of infected nonunion[2].

Infected nonunion of the tibia is a posttraumatic bony wound[3] and not equivalent to hematogenous osteomyelitis. The latter disease is a bacterial intramedullary abscess usually occurring through a hematogenous route into the metaphyseal region of the involved bone. If neglected, the condition creates necrotic bone, which requires surgical intervention and skeletal reconstruction. Apart from the presence of pus, the lesion of hematogenous osteomyelitis of childhood has little in common with that which is caused by trauma.

In a traumatic bony wound there is invasion of bacteria from outside the body. During this process, the local soft tissue and blood supply of bone are

compromised, this creates an ideal milieu for bacterial proliferation[4] .
Whereas successful management of hematogenous osteomyelitis is often the result of an appropriate choice of parenteral antibiotic, a successful outcome to posttraumatic wound of bone requires surgical revision of the wound to prevent further bacterial growth.

Several parameters will help identify infected nonunion of a tibial fracture [3] .

1. Exposed bone that has been devoid of vascularized periosteal coverage for more than 6 weeks,
2. Purulent drainage,
3. Positive bacterial culture from the depths of the wound, and
4. Histological evidence of necrotic bone containing empty lacunae.

To define a infected nonunion of tibia patient’s history and physical examination must be considered first. A history of open fracture, previous surgery, associated with pain & motion at fracture site in the presence of soft tissue swelling all these suggest infection even in absence of active drainage, systemic symptoms or elevated laboratory parameters.

CAUSES [5]

Infected nonunion can develop –

1. After an open fracture
2. After a previous open reduction and internal fixation (ORIF)
3. Sequelae to chronic hematogenous osteomyelitis.

The open fracture is the most common cause of infected nonunion and the tibia is the most commonly involved bone in the infected nonunion after an open fracture. Because of increased trend for operative fracture surgery,infected nonunion after implant surgery has increased in incidence [4].

PATHOPHYSIOLOGY OF POSTTRAUMATIC OSTEOMYELITIS [6,7,8]

Osteomyelitis is a frequent complication of trauma induced open fractures. This is especially true of fractures associated with severe soft tissue injury. Osteomyelitis is notorious for its tendency to recur, even after years of quiescence. It has been proposed that cure is not an appropriate word to describe the outcome of treatment of osteomyelitis, that the best one can hope to accomplish is arrest.

The stages in the pathophysiology are-

1. Entry of pathogens
2. Establishment of infection

3. Interference in host reaction to infection
4. Damage to the host
5. Persistence of infection.

1. ENTRY OF PATHOGENS

To accomplish this microbial pathogen must breach the mechanical barriers, the skin and mucus membranes, that normally protect the host. Without a break in the skin, as is the case in closed fractures, osteomyelitis is an infrequent complication. The incidence of osteomyelitis is much higher in open fractures when bacteria have the opportunity to enter the wound directly from the environment. Clostridium perfringens associated with farm injuries, Pseudomonas aeruginosa and Aeromonas hydrophila after injury in fresh water, and Vibrio and Erysipelothrix infections with salt water contamination. However, although most wounds are contaminated with bacteria at the time of injury, most cases of posttraumatic osteomyelitis are caused by hospital acquired pathogens such as coagulase positive staphylococci or enteric Gram negative bacilli, including Pseudomonas aeruginosa.

2. ESTABLISHING INFECTION

The presence of bacteria in a wound is not sufficient to cause infection. Approximately 60% to 70% of open fractures are contaminated by bacteria, but a much smaller percentage go on to infection.

Factors that help in establishment of infection are-

1. Damage to the local soft tissue & bone –There is 30%-40% risk of infection in type 3B open fractures . Traumatized soft tissue and bone expose potential binding sites for bacteria such as collagen. Staphylococcus aureus, the most common cause of posttraumatic osteomyelitis, has receptors for numerous host proteins including collagen.
2. Compromised blood supply- Necrosed tissue act as foreign body .
3. Implants used for stabilization serve as additional foci for colonization of bacteria.
4. The instability of fracture

Once attached to the host surface, many bacteria have the ability to adhere firmly by producing biofilm. Biofilm (protective covering over bacteria under which colonies thrive) forms strong bonds with the glycoproteins of the tissue substrate. Biofilm protects bacteria from the action of antibiotics, inhibits phagocytosis, impedes the ingress of antibodies, and impairs T lymphocyte and B lmphocyte function.

3. INTERFERENCE IN HOST REACTION TO INFECTION

The initial host response to infection is an acute inflammatory reaction, which fight against the bacteria. But trauma has been reported to delay the inflammatory response, depress cell mediated immunity, the function of polymorphonuclear leukocytes, including chemotaxis, superoxide production, and microbial killing.

The presence of a foreign body at the site of infection, usually in the form of a metallic fixation device or prosthetic implant, can inhibit the efforts of host defense mechanisms. Metals used in these devices stimulate production of cytokines and impair lymphocyte activity.

Dean et al found that Cr and Ti inhibit mitogen stimulated T cell and B cell proliferation,and inhibited the production of IL-2 and INF-gamma.

4. DAMAGE TO HOST

Although the primary goal of initial inflammatory response is to destroy bacteria and contain the spread of infection, proteolytic enzymes released by phagocytes also can damage surrounding tissue. Certain bacterial products, such as the leukocidins of Staphylococcus, may promote this destructive role of neutrophils.

Bone resorption is also a feature of osteomyelitis. Osteopenia and weakened bone may predispose the patient to pathologic fractures. If a fracture already is present, bone resorption may delay or prevent its healing. Bacterial products, such as lipopolysaccharide of Gram negative bacteria and surface associated protein of Staphylococcus aureus are stimulators of bone resorption.

Proinflammatory cytokines - IL 1beta, IL-6 and TNF-alpha are released in the acute inflammatory response to injury and infection , and are the most important mediators of bone resorption. Systemic effects of osteomyelitis also may arise, but are not common. Adjacent joints may become infected by contiguous spread, or bacteremia can carry infection to metastatic sites. Staphylococci and Streptococci also have the ability to cause toxic shock syndrome.

5. PERSISTENCE OF INFECTION

Factors contributing to the persistence of infection are – Local tissue damage, deranged host immune system , fracture instability, formation of biofilm by the infecting organisms and bacteria with surface adherence (resistant to antimicrobials even in absence of biofilm).

INVESTIGATIONS

The following investigations will help in the diagnosis of infected nonunion

HEMATOLOGIC INVESTIGATION

An elevated leukocyte level or Westergren erythrocyte sedimentation rate can be consistent with ongoing deep bony infection, although they are not necessarily diagnostic [9]. Normal levels can be found even with active drainage in which there is little surrounding cellulitis or systemic involvement. Metabolic parameters such as an evaluation of glucose tolerance, renal function, and liver functions (particularly protein levels) should be considered before beginning operative reconstruction.

RADIOGRAPHIC STUDIES

Several radiographic features, such as cortical irregularity, perisosteal reaction, alteration in normal mineralization, or the presence of a bony sequesturm have been associated with deep bony infection, in the presence of an ununited fracture (and especially in association with previously implanted metal internal fixation devices) [10].

BONE SCAN

The triple-phase Technetium 99-MDP (Methylene diphosphate) bone scan can help to distinguish an inflammatory condition from a deep bony infection, yet it also can be compromised by ongoing reparative activity [11].

The 67-gallium citrate isotope may accumulate at the site of infection or inflammation by virtue of an increase in the permeability of the local vascular structures, the isotope being taken up by microorganisms and some elements present in the inflammatory exudates. Because any process leading to reactive bone formation will result in increased uptake of 67-gallium citrate, the scan suggests a deep bony infection only when the focal uptake is inconsistent with that seen on the

technetium 99-MDP scan. If a similar pattern exists, the 67-gallium scan must be substantially greater in uptake than that of the technetium-99 MDP scan to be considered suggestive of deep bony infection. The accuracy rate of this approach has been disappointing, varying from 50% to 60%. [12]

An additional diagnostic approach has been to label leukocytes with 111-indium. In a study comparing indium to sequential technetium and gallium scans, the overall sensitivity rate was 83%, with a specificity rate of 86% and an accuracy rete of 83%, yet false results have been attributed to problems with the technique of leukocyte labeling.

TISSUE BIOPSY

The tissue biopsy remains the most convenient and accurate method to identify ongoing deep bony infection , inspite of all advances in diagnostic imaging & lab evaluation.

CLASSIFICATION OF INFECTED NONUNION TIBIA

Classification must be made after soft tissue & skeletal debridement. Several classifications exist-

1. Weiland's [13] (on extent of infection)-

   Type 1- Bone exposed and soft tissue infection present.

   Type 2- Circumfrential cortical & endosteal infection present.

   Type 3- - Circumfrential cortical & endosteal infection with segmental bone loss present.

2. Gordon & Chiu's (on severity of underlying bone damage.) [14]

   A- Tibial defect & nonunion without substantial bone loss (< 3cm)

   B- Tibial defect >3cm with intact fibula

   C- Tibial defect >3cm with nonunion fibula

3. University of Texas classification-(location of infection and immune competence of the host)

   1- Intramedullary ; 2-Superficial; 3- Local;

   4- Diffuse with segmental boneloss.

   Host immune system-

Type A- Healthy with adequate soft tissue cover;

Type B- With local or systemic compromise;

Type C-Severely compromised, contraindicated for surgical reconstruction.

4. May et al [3] -

Type 1- An intact tibia & fibula that can withstand functional loads. The skeletal involvement is unicortical & debridement can be done without any threat to skeletal integrity.

Type 2- An intact tibia with bone graft needed for structural support.

Type 3- A tibial defect </= 6cm with intact ipsilateral fibula.

Type 4- A tibial defect > 6cm with intact ipsilateral fibula.

(The defect > 6cm can not be bridged successfully by autograft alone)

Type 5- A tibial defect > 6cm & no usable fibula.

5 Dror Paley-

A1- Mobile atrophic, Bone loss <1cm ,

A2- A2.1- Stiff hypertrophic without deformity, bone loss <1cm

A2.2- Stiff hypertrophic with deformity, bone loss <1cm

B1- Osseous defect >1cm, length maintained

B2- Bone loss >1cm, shortening present

B3- Both osseous defect & bone loss with shortening.

5. Jain et al [5] -

Type A - infected nonunion of long bones with nondraining (quiescent) infection, with or without implant in situ.

Type B - infected nonunion of long bones with draining (active) infection. Both are classified further into two subtypes: 1) nonunion with a bone gap smaller than 4 cm or 2) nonunion with a bone gap larger than 4 cm.

TACTICS FOR RECONSTRUCTION

The overall goal in the reconstruction of an infected, ununited tibial fracture involves more than control of the infection and includes creation of a healed, aligned, and drainage –free limb that is functionally better than that which could be achieved by amputation and prosthetic fitting. Several factors must be considered in deciding to reconstruct the bone, including the patient’s age, metabolic status, mobility of the foot and ankle, integrity of the neurovascular structures, and importantly, the patient’s motivation.

Once the decision has been made to reconstruct, the first step is to eradicate infected and avascular bone with surrounding compromised soft tissue. The extent of bony and soft tissue debridement is defined by the presence of punctate bleeding .

The experience with the posterolateral bone graft between the fibula and tibia has suggested that in some cases active infection will become quiescent once the tibia is inherently stable.

Skeletal Stabilization

When faced with a skeletal defect and associated bony instability, preserving or regaining functional length and bony alignment must be emphasized. Shortening of the tibia >1.5cm, varus or valgus deformity >10^o to 15^o, recurvatum of >10^o, internal rotation >10^o, or external rotation >15^o all can lead to long – term functional disability. Given that, particularly with more extensive bony defects after debridement, external skeletal fixation has assumed an important role in provisionally managing the unstable tibial skeleton after operative debridement. [15,16]

Soft tissue reconstruction-

Important issues to be considered-

1. As a general rule, use of parenteral antibiotics should be delayed until the time of soft tissue coverage. This will minimize the possibility that the organisms identified at the initial debridements will become resistant to the culture-specific antibiotic. [17]

2. Timing- In most instances, soft tissue coverage is delayed until the extent of the bony and soft tissue infection has been identified and the base of the wound has become vascular. This is best defined as a wound that will support granulation tissue.

The possibilities are from skin graft to free tissue transfer. Several local pedicled muscle and myocutaneous flaps exist in and about the tibia, including the gastrocnemius and soleus flaps in the leg [18]. At the distal third of the leg, flaps such as the extensor hallucis longus and peroneus brevis have been developed, although they are not used widely. Free muscle flaps, including the latissimus dorsi, gracilis, tensor fascia lata, and rectus abdominus have been the most reliable means of coverage from the mid tibial level distally.

The experience of several authors suggest a high rate of success using microvascular free tissue transfers, and these have become in many cases the preferred method for soft tissue reconstruction, in contrast to pedicle flaps, cross-leg flaps, or both. [14,19]

In the presence of large bony defects that require reconstruction, antibiotic-impregnated methylmethacrylate beads can be used to fill the dead space, in which later bony reconstruction can be done.

Bony reconstruction

1 Open cancellous bone grafting-

Papineau technique [20] - consists of packing a skeletal defect with minced cancellous bone without overlying soft tissue coverage. most applicable when treating patients who have a metaphyseal skeletal defect associated with a limited zone of soft tissue loss.The method will be successful only if the wound is sufficiently cleaned and well vascularized to support the growth of granulation tissue.

The disadvantages involve an inadequate local blood supply, which may not provide for adequate granulation tissue; considerable time needed between bone grafting and wound coverage; and a long delay between bone graft incorporation and its remodeling to develop the intrinsic strength to withstand functional loading.

2. Posterior bone grafting and tibiofibular synostosis- [21]

Advantages - a relatively straightforward surgical approach that avoids the zone of trauma and previous infection and incorporates an intact fibula into the overall structural integrity of the lower limb. Autogenous cancellous grafts can be harvested from the iliac crest and placed in a relatively well-vascularized environment beneath the posterior muscles of the lower limb, facilitating rapid revisualization and graft incorporation.

The disadvantages associated with the posterolateral approach include potential injuries to either the peroneal or posterior tibial artery. Because many of these limbs may have been injured by high-energy trauma, they may have only one remaining arterial pedicle. Thus when considering this approach, the physician might consider obtaining a preoperative arteriogram.

3 Anterior cancellous bone graft beneath a flap

The timing of this approach depends on the location of the bone loss, the type and location of muscle flap, and the extent of tibia bony loss. The flap should have healed sufficiently to withstand another surgical procedure, which suggests a minimal delay of approximately 3 weeks. The surgeon must know the location of the vascular pedicle to the muscle flap in this approach.

The advantage of the anterior cancellous graft beneath a flap is primarily that the bone graft can be placed directly in the defect. Its ability to revascularize and reincorporate is enhanced by the overlying well-vascularized muscle bed.

The disadvantages of this approach involve primarily the danger to the overlying muscle flap.

4 Fibula-pro-tibia transfer [22]

The fibula can be raised on its vascular pedicle and transferred as a vascular zed graft in a single stage. The advantages of this procedure are that the ipsilateral fibula can be used without violating the contralateral leg. The fibula is a straight cortical bone and is often long enough to bridge most defects of the tibia. A fibula transferred with its vascular pedicle intact will hypertrophy when subjected to greater loading stresses. Finally, the cortical structure of the fibula allows bony screws and plates to be used to securely fix the bone in these unstable limbs.

The disadvantage is the limb can become more unstable and fail to unite at either ends of the transferred bone.

5 Vascularized autogenous bone graft

The donor sites from which vascularzed bone grafts can be obtained to reconstruct the tibia include the fibula, the iliac crest, and the ribs. Although the iliac crest offers some theoretical advantages in that it can be elevated as a composite osteocutaneous or osteomyocutaneous flap, difficulties with its shape, size, and strength have limited its application.

Yajima et al [23] in their series of use of vascularised bone graft stated bone union to occur in 7months for femur and 6months for tibia. The disadvantages being donor site morbidity and graft can only bridge the gap but shortening is not addressed. In other series, the osseous union has occurred between 16 to 30 weeks after transfer. Given its technical complexity, however, application of the technique is limited to centers with experienced microvascular surgeons.

6 Nonvascular autogenous cortical bone grafting

Disadvantages- Need for prolonged support and the fact that the graft may continue to weaken as it revascularizes, reaching a maximum weakness 12 to 48 weeks after transfer. Furthermore, it may take years for the graft to hypertrophy sufficiently to withstand functional loading.

7. Transplant of allograft

The disadvantages of the allograft transfer in a patient with a history of infection are those primarily related to the inherent potential for the allograft to become a sequestrum should residual organisms remain in the recipient site.

8. Distraction Histogenesis

The technique involves corticotomy and slowly transporting the segment along with soft tissue envelope, supported by flexible ring external fixator.

The advantages of this technique, if it is successful, are that the reconstruction can require only one surgical procedure. It can restore skeletal length and alignment, osseous union, and functional rehabilitation while the external ring frame is in place. A contracted, avascular soft tissue envelope may not be a contraindication to this approach, although it has been found that the procedure can be made substantially easier if the traumatized soft tissue is replaced by a muscle flap before bony reconstruction.

The disadvantages – It is time consuming, as several months are needed to regain skeletal length and additional months are needed before the immature bone that formed during the distraction becomes stable enough to withstand functional loading. The device is cumbersome, technically difficult to apply, and often is uncomfortable for the patient.

The use of the concept of bone transport stems from earlier attempts by surgeons to overcome limb length discrepancy by limb lengthening. In the late 19^{th} century Alessandro Codivilla pioneered the concept of limb lengthening but his methods were primitive and fraught with problems. His successor Vittorio Putti devised a relatively safe procedure for limb lengthening. he fashioned an instrument called osteoton for operative lengthening of the femur . He achieved this by producing a fracture of the shaft and used two large pins in the proximal and distal fragments. In addition he used a telescoping tube which could be attached to the pins by metal sockets and these tubes were used to provide traction on the pins with a powerful spring. Two scales divided in millimetres gave the surgeon the measure of traction and the length distracted. A screw was used to operate the spring. Putti performed Z – Shaped osteotomies similar to that done for tendon lengthening and fixed the traction apparatus and progressively distracted the pins with the patients hip and knee flexed to relax the muscles. When sufficient distraction was achieved he pout the limb in plaster till the callus consolidated. He performed this operation on 10 patients and achieved 3 to 4 inches lengthening in 1918. He reported delayed consolidation of the callus in all and neurogenic pain in one patient in the sciatic and tibial nerve dermatomes [24].

Patterson [25] in his review on leg lengthening highlights the work of Anderson. Boyd et al and surgeons like Wagner, Western and Kawamura, which led to the rekindling of interest in limb lengthening. This led to the concept of bone transport by callus distraction.

Wagner [26] performed limb lengthening in 58 patients under the age of 17y during 1972 to 1978. He developed an external fixator which could be used to distract the femur and the tibia after an osteotomy. He performed satisfactory lengthening up to 7cm and published his results in his review.

The Concept of using the ring fixator for this purpose and the usage of the principle of internal bone transport to fill bone defects which result from excision of infected bone was, popularised by Gavriel Abramovich Ilizarov of Kurgan who after a series of experiments on animals published a treatise on the tension – stress effect on various tissues.

TREATMENT BASED ON CLASSIFICATION

Accoring to Jain et al [5] -

Type A1 (Quiescent infection with bone defect less than 4cm)- Single-stage debridement and bone grafting with fracture stabilization are the methods of choice.

Type B1 (Draining infection with bone defect less than 4cm)- Adequate debridement, fracture stabilization, and second-stage bone grafting gives desirable results .. Type A2 (Quiescent with bone defect > 4cm) and Type B2 (Draining infection with bone defect > 4cm) – Debridement and Distraction histiogenesis is preferred.

According to Dror Paley's classification- (Modified by Maurizio Catagni [27]

Classifn.	PATHOLOGY	TREATMENT
A1	Mobile atrophic nonunion with bone loss less than 1cm.	Excision of the atrophic ends & BIFOCAL osteosynthesis
A2.1	Stiff hypertrophic without deformity & bone loss less than 1cm.	MONOFOCAL osteosynthesis
A2.2	Stiff hypertrophic with deformity & bone loss less than 1cm.	MONOFOCAL osteosynthesis and correction of deformity
B1	Osseous defect more than 1cm with length maintained	
B1.1	Defect 1cm- 5cm	BIFOCAL osteosynthesis
B1.2	Defect more than 5cm	TRIFOCAL osteosynthesis
B1.3	Defect more than 8-10cm	TRIFOCAL osteosynthesis & transport using crossed longitudinal olive wires.
B2	Bone loss more than 1cm & shortening present	
B2.1	Shortening less than 5cm	BIFOCAL osteosynthesis of tibia with fibular osteotomy.
B2.2	Shortening more than 5cm	TRIFOCAL osteosynthsis with fibular osteotomy.
B3	Both osseous defect and bone loss with shortening	Bone transport is done till nonunion site is docked and then lengthening continued in order to eliminate shortening.

ILIZAROV FIXATOR AND DISTRACTION HISTONEOGESIS:

HISTORICAL REVIEW

Prof. Gavriel Ilizarov was born on 15 june 1921 in Russia .He graduated from medical school in 1944. Without any practical training he was sent to a War torn region of Kurgan in north Siberia .There were many soldiers who had posttraumatic osteomyelitis with nonunion of long bones. In 1951, out of sheer necessity he developed a revolutionary technique and called it a RING FIXATOR .With this fixator he saved limbs and lives of many soldiers. Word of his success was largely ignored by the mainstream medical authorities in Russia until in 1967, Valery Brumel, an Olympic champion high-jumper and national hero had an infected tibial nonunion after a motorcycle accident. After 14 failed operations, he was finally referred to Dr. Ilizarov. Brumel was treated with the Ilizarov technique and one year later jumped 2 meters in a high jump competition. After this, word spread like wildfire. Ilizarov was granted permission and funding in 1971 to build the Institute of Orthopaedics in Kurgan. The center is now known as the Russian Ilizarov Scientific Centre for Restorative Traumatology and Orthopaedics.

Ilizarov’s experiments stress the importance of fixator stability. Secure (rigid) fixation limits translation micromotion between bone fragments, which inhibit union, damages local circulation and leads to formation of bone through fibro cartilage. Stable fixation, active muscle function and weight bearing enhance local circulation and shorten the period of osseous callus formation and remodeling. Axial distraction of callus produces osteoneogenesis similar to membranous ossification.

Biomechanically [28] axial stiffness (the ability of the fixator to resist gap closure between bone ends) showed the greatest difference between Ilizarov and conventional external fixators. The Ilizarov fixator showed low axial stiffness to axial loading (75% less compared to conventional) and high axial stiffness on bending loading. Centering of the wires was associated with lower axial stiffness than offset configuration.

The reason 1.5 or 1.8mm wires are used is to optimize the low stiffness property while maintaining sufficient strength to resist breakage or plastic deformation.

Bagnoli showed that for Ilizarov wires yield point is 120Kg/sq mm , that is 210Kg for 1.5mm wires and 305Kg for 1.8mm wires. Usually the optimum tension applied is 105Kg for 1.5mm and 150kg for 1.8mm. The Lecco group (Head quarter of Italian A.S.A.M.I) routinely use 130kg for full ring and 90Kg for half rings.

Factors affecting the stability of Ilizarov apparatus can be [28]

I Apparatus related (Extrinsic)

II Intrinsic factors

I. Apparatus related (Extrinsic)- Factors increasing the stability are

1. Increase in number, diameter and tension of the wires.
2. The angle between the wires- spread of wires approaching 90 degree.
3. Increase in number of rings.
4. Decreased ring size (wire span distance of 2-3cm around the limb)
5. Close positioning of center rings to fracture or nonunion site.
6. Use of olive (stop) wires.

II. Intrinsic factors-

1. Area of tissue contact between the bone ends.
2. Modulus of elasticity of tissue between bone ends
3. Length of gap between bone ends.
4. Tension of soft tissue surrounding bone.

The stability of the fixator depends on the understandings of biomechanical principles important for the correct application of the apparatus. Inadequate fixator stability not only reduces new bone formation but also causes pain and pin related sepsis. A frame producing pain leads to decreased functional use, limitation of joint movement and less weight bearing in the limb, all of which result in progressive osteoporosis. Increasing fixation instability further inhibits functional limb use, creating a cycle of discomfort and disuse that characterizes reflex sympathetic dystrophy: altered vascularity, stiffness and osteoporosis.

Principles in the method of application of ring fixator-

The wires are introduced taking in to consideration the topography of vessels, nerves and tendons. The first principle of wire insertion technique is to prevent thermal injury to skin, soft tissue and bone when drilling a wire through cortical bone. Heat build up can be reduced by using a bayonet shaped wire tip. To further reduce thermal damage the wire should be introduced in a start and stop fashion while the wire is being irrigated to conduct away the heat. The wire should be introduced through the soft tissue straight to bone before drilling and similarly after the tip emerges through the opposite cortex, the wire should be driven by hammering on the blunt end to prevent tissue being caught by the spinning tip [29].

To ensure maximum joint movement of a limb in a circular external fixator the muscle being penetrated should be stretched at the time of transfixion. This means that an adjacent joint must be flexed as the wires pass through extensor surface of the limbs and extended as the same wire traverses the flexor musculature. Adjustments must be made in the skin position before wire insertion. The skin should be displaced away from the fracture site to provide maximum skin for elongation. While securing wires to the rings, the ring must be fixed to the wire and not the wire to the ring. If the wires are bent to attach them to the frame they will throw abnormal stress on the bone, which will cause displacement of the fragments and soft tissue. Tension in the wires may decrease after surgery due to deformation, osteoporosis and other causes. Periodic retensioning of wires may be necessary especially during compression osteosynthesis [29] .

Distraction osteogenesis- The concept of callotasis (callus distraction) or distraction osteogenesis was studied in depth by Ilizarov and his associates by performing animal experiments. Its application in infected nonunion was worked out in his institute. His work on this concept led to the use of the Ilizarov fixator and its many ensuing modifications in the treatment of difficult nonnions. The advantages of the system as worked out and theorised by him are a follows [29,31].

1. The use of a cicular fixator provides multiaxial stability which is important for the promotion of the union of fractures. The use of tensioned 1.5 to 1.8mm Kirschner wire (K-wire) was the key to the

rigidity of the system while still providing for axial loading which greatly enhances the chance of union at the site of the nonunion and prevents osteoporosis of immobilization.

2. The ideal rate of distraction osteogenesis was ingeniously worked out and found to yield best results at 1mm per day in multiple fractions during the day. He designed an auto distractor which could distract the callus upto 60 times a day over 1 mm distance to achieve a uniform and good quality callus. For best clinical results he recommended distraction in 4 installments of 0.25 mm each. Doubling the rate of distraction requires that two corticotomy sites be used, proximal and distal. At this rate the regenerative potential for the bone may exceed that for surrounding tissues. The tendency is to develop musculotendinous contracture and joint contracture, paraesthesia due to peripheral nerve stretching and rarely traction injury to vessels resulting in ischemia. These complications can be avoided if patient maintains normal function during procedure

3. His experiments on the effects of sustained graduated traction on skin, muscle, facia. nerve and blood vessels have resulted in knowledge of added benefits of being able to bridge soft tissue defects that are commonly met with in the management of infected

nounuinion. This obviates the need for complex soft tissue transfers that would otherwise be necessary.

4. Ilizarov also described techniques by which commonly associated problems like bone defect, angular deformities, rotational deformities and limb length discrepancy could be overcome with his ring fixator simultaneously thereby providing a single solution to this multifaceted problem of infected nonunion.

5. Probably the most significant but inadequately recognized contribution of the Ilizarov system to the problem of nonunion associated with infection is the vascular response of the bone and the limb to distraction osteogenesis. Whether this vascular response of the limb is the cause or the effect of the callotasis is not known, but the benefits of this probably is vital in the fight against infection. This is also probably the reason why Ilizarov reiterates the fact that antibiotics were never needed and that "infection dies in the fire of distraction osteoneogenesis".

6. Ilizarov also stressed on the beneficial effects of weight bearing (load) on the regenerate. This is one of the major advantages provided by the type of stability afforded by the fixator, which is

also advantageous for union as well as preventing osteoporosis associated with immobility.

The one other contribution of his work in this field, though of controversial significance, is the technique of corticotomy (compactotomy), which he recommended. He stresses on the maintainance of the integrity and continuity of the periosteum and the endosteal blood supply. However this theory has been countered by various subsequent experiments and observations. Those who advocate an osteotomy [31] state that -

1. The period of delay in distraction is sufficient for re-establishment of the intramedullary vasculature.

2. Often attempts at corticotomy leads to inadvertent disruption of the periosteum especially in the posterior portions and often ends as an osteotomy.

3. Some investigators have found no significant difference in the quality of the regenerate following corticotomy and osteotomy.

To study the tension stress effect on the growth and genesis of tissue, Ilizarov performed corticotomies on dogs and used various models of ring fixators with variable number of rings and tensions in the K-wires and periodically studied the microscopic changes in bone and soft tissue. He submitted the callus to varying rates of distraction and compared their microscopic qualities and published a series of articles on the tension-stress effect [29,31].

His observations can be summarized as follows. When callus is distracted at 0.5mm a day at frequency of 0.125 mm every 6 hours, osteogenesis overtook the speed of distraction causing premature consolidation. A rapid rate of distraction of 2 mm per day retarded osteogenesis and also caused detrimental changes in the soft tissue surrounding the site of distraction. Elongation by 1 mm per day in 4 equal installments led to more favorable results. At a given rate of distraction, a greater frequency provided a better outcome. With 1mm per day distraction, the autodistractor proved superior to a distraction frequency of 4 times per day which in turn was better than once a day. Histochemical studies also showed a higher level of tissue alkaline phosphatase and ATPase activity at 1mm distraction per day with autodistractor at 0.017 mm every 24 minutes. He believes that osseous tissue possesses a previously hidden biologic plasticity that can be unveiled with appropriate conditions of osteotomy, fixation and distraction. With the techniques he developed the surgeon can create a growth plate any where in the bone. This physis–like structure ossifies in both the proximal and distal directions from a central growth zone during distraction. Under ideal conditions of fixation and distraction, neo-osteogenesis proceeds directly from marrow tissue without the formation of an intervening cartilagenous layer. In this sense, the growth zone of the distraction regenerate resembles intramembranous ossification. Morphologically the parallel columns of osseous tissue and vascular channels resemble the zone of primary osteoid in the physis [29].

Radiographic classification of regenerate-(Maurizio Catagni) [32]

1. Normotrophic- Early radiodense new bone formation occurring approximately 20days after corticotomy. Definite columns of longitudinally oriented new bone appear extending from the corticotomy surface toward a central, transverse radiolucent area approximately 4mm in height.
2. Hypertrophic – The regenerate appears before 20 days after corticotomy. Cross-sectional diameter of regenerate exceeds that of corticotomy site . Premature consolidation occurs if distraction is done at 1mm/day. Factors leading to hypertrophic regenerate are- young age, more active and with good local blood supply within circumferential muscle beds.

3. Hypotrophic – Regenerate does not appear even by 30 days , the bone columns themselves contain multiple breaks(radiolucencies) and the overall shape of regenerate is hourglass appearance. Factors causing this include prior surgery in corticotomy site with known vascular deficit, local scarring or swelling which constricts the new tissue formation and lack of function or weight bearing by patient. In these cases rate of distraction has to be slowed down.

Ilizarov also studied the electron microscopic structure, cellular morphology and biochemistry of the regenerate. The first response to the corticotomy is an inflammatory reaction similar to that seen in fracture healing. Once distraction begins, fibroblast–like cells appear in the gap with their long axis parallel to the vector of elongation. Under electron microscope the elongating fibroblasts contain abundant endoplasmic reticulum, prominent nucleoli and foetal development. The fibroblast–like cells are metabolically and biosynthetically active and produce collagen molecules. These collagen fibers align parallel to the vector of elongation, condensing proximally and distally away from the centre of the distraction gap. Simultaneously capillaries form between the bundles of collagen that are oriented parallel to the vector of tension stress. With capillaries, osteoid producing osteoblasts appear along the collagen fibers. Under ideal conditions there is a zigzag area of about 2 to 4 mm width which is relatively avascular at the middle of the distraction zone. During the neutral fixation period that follows distraction, the central growth zone gradually ossifies while simultaneously the regenerate in the gap forms a cortex that blends with and eventually becomes indistinguishable from the original cortex [29].

Ilizarov studied the effect of distraction on nonosseous tissue [31]. *Fascia* has a wavy appearance under light microscope. Distraction at the rate of 1 mm in one step every 24 hours caused fascial collagen fibers to lose their normal wavy structure by 14 days and stain unevenly due to pronounced swelling and focal homogenization. When distracted in 4 steps at the rate of 1 mm per day, by 14 days, slight swelling in some fibres and less waviness than in fibres of undistracted control limbs is seen. Along the periphery small accumulations of undifferentiated fibroblast–like cells appear, indicating stimulation of tissue growth. In animals, fascia distracted at 1 mm per day in an auto distracter they appeared almost normal and showed greater accumulation of undifferentiated cells .

Arterioles in the distraction region showed marked increase in biosynthetic cellular activities that parallel the growth of tissue structures under the influence of the tension stress effect at optimal rates. At six hourly distraction of 0.25mm there was an increase in the volume of cytoplasm enriched with organelles and in the length of intracellular contents, both characteristic of actively growing vessels. With ideal distraction rates, marked hypertrophy of organelles was noticed within the cytoplasm of vascular smooth muscle.

Nerves -When distracted with autodistractor at 0.017mm every 24minutes , nerves appeared similar to that of developing foetal nerve trunk. When distracted once a day by 1mm, uneven diameters of axons and irregular accumulation of cytoplasm were seen. These changes were less pronounced at a rate of 2mm per day in 4 steps.

Skeletal muscle- During elongation under the influence of tension stress effect skeletal muscle demonstrated ultra structural changes in both energy supplying and protein synthesizing systems. The energy providing mitochondria is hypertrophied and displayed an enlarged amount with multiple cristae especially in sections obtained from the ends of muscle fibers and from the subsarcolemmal regions where actin and myosin myofilaments were being synthesised on the polysomes. The functional activity of the nuclei were enhanced and characterized by hypertrophy of the nucleoli and the appearance of deep karyolamellar invaginations. Muscle growth under the influence of tension stress occurred not only by myofibirillogenesis in preexisting muscle fibers but also by formation of new muscle tissue as demonstrated by the increased number of satellite cells, the appearance of myoblasts and their fusion into myotubes. Within the newly formed muscle fibers active formation of myofibrils and sarcomeres took place.

Skin- The cellular elements of the skin also showed signs of activation as a result of tension stress mainly in the basal cell layers of the epidermis. Basal cells acquire a highly cylindrical shape with their long hyperchromatic nuclei oriented towards the long cellular axis. As a result of this proliferation, the number of basal cell layers and consequently the thickness of the skin increased considerably up to 10 layers compared to 3 to 5 layers in control limbs. Skin appendages were also activated as demonstrated by the increased number of hair follicles, sweat and sebaceous glands.

There is reason to believe that all is not well at distraction rates of 1 mm per day in 4 or more increments. In experiments conducted on rabbits, Simpson et al [33] - Using Orthofix application on the medial side of tibia with mid-diaphyseal osteotomy, found that muscles respond adversely to distraction rate of more than or equal to 1mm per day. In their studies they found evidence of muscle damage when distracted at rates greater than 0.4mm per day. Damage was indicated by the presence of fibre splitting, central nuclei, abnormally shaped fibers and necrosis. In animal models these investigators found greater loss of dorsiflexion than plantar flexion. Histological examination of these muscles showed significant abnormalities in muscles lengthened at rates higher than 0.4 and 0.7 mm per day with a strong correlation between rates of distraction and histological appearance. In a cross section of the muscle, the percentage of completely damaged fibers rose in an exponential manner with an increasing rate of distraction. The main abnormalities were whorled fibers and centralization of nuclei. These indicate abnormalities of the contractile thickening of the endomysium and perimysium at rates of 1 mm per day and above. At more rapid rates such as 2.7mm per day there were gross changes with necrosis and disorganization of muscle structure.

Similar reports of loss of 30^{o} range of movement which reappeared after sectioning of flexor and extensor muscles following transport of bone in the limbs of dogs are available from Christian Delloye et al [30] . In the same study Delloye reported no significant alternation in the quality of callus following osteotomy and corticotomy. This has been demonstrated both in microscopic examination of callus and in microangiographic studies which did not show significant changes in marrow vascularity. However periosteal contribution to callus formation was seen in microscopic studies.

Bone marrow was found to be the largest contributor to the amount of interfragmentary callus.

Yasui, Kojimoto and Saski[34] with the help of micro angiographic studies were able to demonstrate a complete restitution of the intramedullary vessels after complete osteotomy. They performed this study because of the difficulty in achieving a genuine corticotomy with the preservation of intramedullary blood vessels. They emphasize, “no matter how carefully the anterior and the mediolateral cortex is cut, the process of manual fracture of the posterior cortex could easily damage the endosteal blood vessels”. They performed osteotomies in 32 Japanese white rabbits, stabilized with ring fixators and distracted at varying rates after a delay of 10days. Microangiography was performed periodically. They found adequate intramedullary vasculature after 10days and during various stages of distraction. Continuity in vasculature was present throughout distraction when the distraction rate was 0.7 mm every 12 hours. They also found no significant difference in callus formation in rabbit bones, which underwent osteotomy and corticotomy.

Kojimoto et al [35] in their study of callus distractions considered preservation of periosteum more important than careful corticotomy. Their results demonstrate that endosteum and bone marrow are not the only contributors to callus formation.

THE ILIZAROV FIXATOR- USE IN INFECTED NONUNION TIBIA :

There are many reports of treatment of infected nonunion of long bones using Ilizarov fixator available in the literature. There are many methods to deal with this condition but none of the techniques except the Ilizarov ring fixator have the ability to correct deformities, eliminate long duration antibiotics, regenerate new bone without the use of bone graft, progressively lengthen the extremity and to allow weight bearing simultaneously during the treatment.

In 1988 Dror Paley, Catagini, Catanco et al[36] published their results. They reported 25 cases, 13 of which were infected. All patients in the study achieved union. One patient had tibio-fibular synostosis, which when combined with fibular hyperplasia, produced sufficient stability to preclude union at the tibia nonunion site. Three of the infected patients had drainage at follow up. Four patients had residual deformity of more than 7^{o}. One patient had residual limb length inequality of more than 2.5cm. According to the A.S.A.M.I system of grading the result, 18 had excellent bone results, 5 were good, 2 were fair and none were poor. Sixteen had excellent functional result. 7 were good, one was fair and one was poor. This study however included patients who had no evidence of infection also.

Green et al[37] reported a series of 17 patients of which 9 had septic nonunions in 1991. Sixteen of these patients eventually united. Seven patients required bone grafting, 6 at the nonunion site and one at the corticotomy site. One patient had amputation for persistent nonunion.

In 1991 Cataneo, Cataginin and Johnson[38] reported 28 patients with infected non-union of the tibia. Six of these patients had hemi circumferential bone loss and were treated with bone transport following anterior hemi circumferential corticotomy. Infection was eradicated in 23 of the 28 patients. All fractures united but three had refractures at the nonunion site due to premature removal of the frame. They were successfully treated with re-corticotomy and circular fixator. No Patient required bone graft, microsurgery or skin grafting. Twenty-one had good functional rating and others had fair rating.

In 1995 Dendrions et al.[39] reported 28 infected nonunion of the tibia treated with Ilizarov fixator. Fourteen patients had excellent bone union, 8 were good, 1 fair and 5 poor results . Functionally seven had excellent rating. 11 good 4 fair and 4 were poor. One had a refracture and opted for amputation. All patients had eradication of infection. The infection was considered as quiescent - when wound was not draining for at least 3m, active but no drainage- when there was abscess or fever and active with drain - when the wound continued to discharge.

Cierny et al [40] studied treatment of segmental tibial defects comparing conventional (debridement and bone grafting) and Ilizarov methodologies. They noticed that Ilizarov method had several advantages –

1. The bone regenerate is exactly the right size for the anatomic site. Massive cancellous grafts undergo a 20 to 40% volume loss in B-hosts(like infected nonunion tibia), fibular transfers require years of hypertrophy to reach a volume match.
2. The wound margins can be approximated after debridement and shortening in Ilizarov methodology.77% of the conventional group required soft-tissue reconstructions but only 14% of the Ilizarov patients required coverage at the docking site.
3. The transfusions and ancillary procedures were few in the Ilizarov group.
4. Long duration pareteral antibiotics were needed in the conventional group.
5. Osteoporosis is also complication in the conventional group.

They concluded that segmental tibial defects are successfully reconstructed using conventional and Ilizarov methodologies. The final result in the two treatment groups were the same. The Ilizarov group proved faster, safer in B-hosts (Infected nonunion), less expensive, and easier to perform.

In a study by Bobroff et al [41] treatment of large tibial defect (mean 9.45cm) treated by Ilizarov bone transport with single corticotomy from 1990-1999 revealed External fixation index of 2months per cm (longer in smokers) and complication rate of 3 per patient. The bone and functional results were good to excellent.

In 2006 Mehmet Kocaoglu et al [42] studied 13 patients with segmental bone defect of femur and tibia associated with infection and these were treated by two stage surgeries, the first being radical debridement with antibiotic bead insertion and 6 weeks later (once ESR , CRP are negative) bone transport to fill the defect using intramedullary nail and an Ilizarov ring fixator. They concluded that this combined method reduced significantly the external fixation index and radiological consolidation index .Mean EFI- 13.5days/cm and mean RCI- 31.7days/cm. The earlier removal of external fixator is associated with increased patient comfort, a decreased complication rate and a rapid rehabilitation. According to the study done by Paley et al in 1997 [43] which compared use of only Ilizarov versus intramedullary nail and external fixator showed

the same results as Mehmet et al but the cost and blood loss were higher in lengthening over IM nail.

But in a study by Kristiansen et al [44] for lengthening of tibia over an IM nail using Ilizarov fixator for constitutional shortness found increased number of major complications (deep intramedullary infection) and slow consolidation (which they thought it to be a result of reduced endosteal blood supply after reaming and lack of soft tissue cover anteromedially for tibia as compared to femur). For these reasons they prefer the traditional callotasis lengthening technique.

In 2007 El-Rosasy et al [45] studied 21 patients with fractures of tibia complicated by bone and soft tissue loss (10 open fractures and 11 infected nonunions) and managed by debridement , acute shortening and relengthening after corticotomy.The mean bone loss was 4.7cm (3-11cm). The relatively safe limits for acute shortening were estimated as: upper third of the leg-3cm; middle third - 3 cm to 5 cm and lower

third- less than 6 cm . During shortening, if the distal blood flow was compromised, compression was released to allow it to return. When the bone defect was greater than the safe limit for acute limb shortening, the limb was shortened to the safe limit and the remaining gap gradually closed at a rate of 2 mm to 3 mm per day. In their

series all fractures united with well aligned limb with no deep infection.

In 1995 Saleh et al [46] compared the results of the treatment of bone defects by bone transport with those of acute limb shortening followed by lengthening. They obtained excellent results in 12 patients (75%) and good in 4 (25%). They found a shorter treatment time and fewer complications with limb shortening and relengthening .

They recommended that acute shortening should be considered for tibial defects of less than or equal to 3cm and femoral defects of less than or equal to 5cm.

Complications of the procedure have been extensively studied by investigators. Complications reported by Dror Paley [47] in an analysis of 46 patients who underwent bone transport for limb lengthening were muscle contracture, joint subluxation, axial deviation, neurological injury, vascular injury, premature consolidation, delayed consolidation, nonunion, pin site problems, implant failure and joint stiffness. Late complications are loss of length, late bowing and refracture. Other relatively rare complications, reported in patients who underwent bone transport for infected nonunion have been skin entrapment at the nonunion site, tendon injury and reflex sympathetic dystrophy. Hypertension and depression have also been reported during bone transport.

Paley [47] has classified undesirable side effects of this procedure into problems, obstacles and complications. Problems were defined as difficulties that arise during the course of treatment that were fully resolved without operative treatment by the end of treatment period. An obstacle was defined as one, which was resolved completely by the end of treatment period with operative intervention. A true complication was a local or systemic effect that remained at the end of treatment or occurred after the end of the treatment. Minor complications, according to Paley, were of nuisance value, but major complications result in functional impairment and could assume medico-legal significance to the surgeon.

MATERIALS & METHODS

This is a retrospective study done on patients who underwent treatment with the Ilizarov ring fixator system for infected nonunion of the tibial shaft. The nonunion was defined according to Brinker's definition which is as follows- A fracture according to the treating doctor has no possibility of healing without surgical intervention. All the patients had a discharging sinus for a period of at least 3months.

Inclusion criteriae were-

- Diaphyseal & Metaphyseal fracture
- Psychologically stable patients
- Persistent pus drainage for atleast 3months
- Brinker's definition for nonunion

The required information was collected from out patient charts, discharge summaries & inpatient charts. From 2000 to 2005 – 56 patients had Ilizarov fixator application for infected nonunion tibia, and 39 were followed up.

Patient information-

There were 39 patients (39 tibia infected nonunions). All were male. Geographically 21 were from a nearby region (within 150km distance) and 18 were from distant regions (1000-2000km).

Their ages ranged from 22y to 74y (mean of 45.5y). The mode of injury was as follows- 35 had motor vehicle accidents, two were due to wall collapse, one had a blast injury and one a fall from a height.

19 patients had initial treatment in our hospital .Among these 13 had a debridement and external fixator application as initial treatment , four had external fixator application with flap cover and two had closed fracture , were treated by plate osteosynthesis . Two of the local patients had native treatment initially and came with pus discharge .There were 19 smokers and 12 with co-morbid conditions (most common was diabetes mellitus).

The parameters studied were-

Parameter	Parameter	No. of patients
Site of fracture	Proximal third	2
	Middle third	19
	Lower third	18
Type of fracture	Open	34
	Closed	5
Type of infection	Active	21
	Quiescent	18
Condition of soft tissue	Fair	29
	Poor	10
Type of nonunion	Type A	27
	Type B	12

In the preoperative assessment patients were examined clinically and roentgenographically and cultures were taken whenever there was a discharge. The patients with a discharging sinus at presentatation were grouped as having active infection and those with at least 3m of discharging sinus initially which later became quiescent were grouped as having quiescent infections .12 had Methicillin resistant Staphylococcus aureus infection (MRSA) . The condition of the soft tissue cover was considered fair if patient had discharging sinuses & scars of previous surgeries along with edema, poor if along with a sinus there was a flap cover/ Split thickness skin graft /adherent scar. 4 patients had common peroneal nerve injury. Six patients had a valgus deformity.

The average number of previous surgeries were two per patient.

The duration of chronicity (time from fracture to Ilizarov ring application) was 3months-48months (mean 25m). The patient who came after 48m, initially had debridement then after few months external fixator application and later internal fixation with plate osteosynthesis , which got infected. 14 had associated injuries and six had ipsilateral injuries.

11 patients had communition ,Winquist type III or more. The type of nonunion was classified according to Dror Paley's classification as type A

which includes bone loss less than 1cm and type B which includes bone loss more than 1cm.

Preoperatively the type of Ilizarov frame construct was prepared after assessing the patient and the radiograph.

Surgical technique-

At surgery under appropriate anaesthesia the nonunion was exposed and radically debrided inclusive of skin, fascia and muscles. Sequestrae and implants were removed and granulation curetted out .The ends of the bone were excised till fresh bleeding bone was visible all around. Whenever the gap was less than 2cm, acute docking was done. During this the angulation if present was corrected. The frame was fixed to bone with atleast 2 K-wires for each ring.

All K-wires were tensioned before fixing to the ring. Additional Schanz pins were used to improve the stability whenever necessary. Whenever nonunions were close to the ankle joint, joint spanning ring through the calcaneum was applied. The corticotomy was done at the level of metaphyses, carefully separating the periosteum from bone and circumferential drill holes are made with 2.5mm drill bit which were joined using a osteotome to complete the osteotomy. One patient had a diaphyseal corticotomy and distraction of 4cm was done. Fibular osteotomy was done when required. While inserting K-wires care was taken to abide by the safe zones and were stimulated by low voltage current to detect proximity of wires to nerves.

Type of treatment given-

For the purpose of treatment three groups of patients were identified 1. Unifocal osteosynthesis which involved debridement & Ilizarov ring application, 2. Bifocal osteosynthesis with only bone transport and 3. Bifocal osteosythesis where in distraction at corticotomy site was combined with gradual docking at fracture site. 23 had unifocal osteosynthesis, 8 had gradual docking & distraction, 8 had only lengthening.

17 had corticotomy at the time of Ilizarov ring application but one did not distract. 29 had 4 ring construct , 6 had 3 ring, 2 had 4 ring with foot ring and rest 2 had 5 ring construct. The type of regenerate (consolidation) was classified according to Maurizio Catagni – there were 14 patients with normal type and 2 had hypotrophic regenerate. Five patients had bone grafting or bone marrow injection.

Postoperative protocol-

Post operatively distraction started on 7^{th} or 10^{th} day at the rate of 1mm per day. The patients were taught about the distraction, the pin site care and physiotherapy adjacent joints. In patients who showed hypotrophic regenerate and communition during osteotomy were advised to distract 0.5 mm per day. When distraction was combined with gradual docking, the docking at fracture was done at the rate of about 1cm in three days interval keeping a watch on distal neurovascularity.

Post operatively one of the patients had soft tissue defect for which regular dressing & Papineau bone grafting was done. No long term antibiotic treatment was given (average duration of about 2 weeks even in MRSA infection). Short courses of antibiotics & pin track injections using Gentamycin were given for pin track infections. Weight bearing ambulation was taught using crutches in a week time and were encouraged to bear full weight during the treatment.

During the bone transport regular radiographs were done after a week of distraction to confirm the movement & later again repeated after 3 to 4weeks to assess the type of regenerate .After the completion of distraction the ring was kept for about twice the time taken for distraction, with X-rays taken regularly. After consolidation the ring fixator was removed & below knee Patella tendon bearing walking cast applied for 4-6 weeks.

During the treatment patients were encouraged to move the proximal & distal joint. If there is evidence of equinus deformity, tendoachilles stretching & if required TA lengthening (1 patient) was done. Finally when there is evidence of fracture union the dynamization of the ring fixator was done & patient was advised to continue full weight bearing walkig.

The total duration of treatment averaged 15months. The complications were divided in to obstacles, problems & true complications.

During follow up the outcomes analyzed were 1. Union, 2. Complications, 3. EFI (External Fixiation Index), 4. RCI (Radiological Consolidation Index), 5. Bone Results and 6. Functional Results.

1. Union- The fracture was considered to be united when it appeared so roentgenographically , when there was no motion at the site of fracture after loosening of the connecting rods and when the patient was able to walk without pain and had a feeling of solidity of the limb. In patients with transport the union time was considered from the time the fracture ends approximated.
2. Complications- Problem was defined as the difficulty which resolved completely before the fixator removal by non operative means. Obstacle was defined as difficulty which resolved completely before the fixator removal by operative means. True complication was defined as problems that persisted even after fixator removal. The true complications were divided as minor (that did not affect the outcome significantly) and major (that affected the outcome significantly).

3. EFI - The EFI is defined as duration of external fixation in days/amount of lengthening in cm.

4. RCI- RCI is defined as time to appearance of consolidation of atleast 3 cortices in AP & Lat in days/ amount of lengthening in cm.

5. Bone results- According to ASAMI protocol bone results were divided in to - Excellent , good ,Fair and poor considering the union, effectively controlled infection, deformity less than 7degree and limb length descrepency less than 2.5cm.

- Excellent- united, no infection, deformity less than 7degree,LLD less than 2.5cm
- Good - united, any two of the other three criteria
- Fair -union and one of the other criteria
- Poor - Non union or refracture; Union but none of the three criteria.

6. Functional results- According to ASAMI protocol functional results were divided in to - Excellent , good ,fair and poor considering-

   1. Noteworthy limp,
   2. Stiffness of knee/ankle (knee FFD more tha 15 deg, ankle -loss of dorsiflexion of more than 15 degrees compared other side)
   3. Soft tissue dystrophy

4. Pain that reduced activity or disturbed sleep

5. Inactivity (unemployment or an inability to return to daily activities)

- Excellent-Active & no other criteria
- Good -Active but one or two criteria were applicable
- Fair - Active but three or four criteria are applicable
- Poor -Inactive regardless of other criteria

The biostatistical analysis used was Chi square test.

RESULTS

Out of 56 patients 39 patients (69.6%) were followed up. The duration of follow up ranged from 3 y – 8 y (5years 6 months). The total amount of lengthening ranged 3 – 10 cm (mean 6 cm) .

The outcomes analyzed were 1. Union, 2. Complications, 3. EFI (External Fixiation Index), 4. RCI (Radiological Consolidation Index), 5. Bone Results and 6. Functional Results.

1. UNION

37 (95%) fractures united. Two patients had nonunion .The union time ranged 3 – 17 months (mean 9.5, median 6).

TIME TO UNION

The patients were grouped as one in whom the union time was less than or equal to 6 months and other group more than 6 months. 22 patients (56.4%) united within 6 months.

Out of the factors analyzed we observed communition, active infection, type of non union (with gap/limb length discrepancy), open fractures and smoking affected the union time. Factors observed to affect the union time is shown in Table 1. Over all the site of non union did not have affect on union time but however out of 7 patients who had delayed union 4 patients were observed to have lower third fractures.

Table 1– Factors observed to affect the union time

Factors affecting union time	No.of patients with time to union		Total No. of patients
	Union time >6m	Union time <6m	
Communition	8 (73%)	3 (27%)	11
Active Infection	12 (60%)	8 (40%)	20
Type of NU Gap/LLD	7 (58%)	5 (32%)	12
Open fractures	19(57%)	15 (43%)	34
Smoking	11(57%)	8 (43%)	19

The type of treatment – between unifocal and bifocal groups there was no difference in union time (50% in both the groups united within 6 months). On comparing patients with only transport versus gradual docking and lengthening, 5 out of 8 (63%) in the earlier group had union time more than 6 months where as 3 out of 8 (37%) in later group had union time more than 6 months. Early docking of fracture site was observed to shorten the union time.

2. COMPLICATIONS

The patients were grouped as 1- with true complications and 2 - with problems and obstacles. 5 patients (12.8%) had true major complications and

9(23%) had true minor complication. All patients in minor complications had no dorsiflexion but a plantigrade foot.

There were five patients with major complications

1. Reinfection—one patient (Case no. 7)
2. Non union - two patients (Case no. 11 & 17)
3. Refracture – one patient (Case no. 33)
4. Joint stiffness (equinus) and refracture - one patient (Case no 6)

Apart from this, one patient had knee stiffness following transarticular external fixator application for soft tissue injury involving quadriceps mechanism. This patient continued to have knee flexion deformity of 15 degrees after Ilizarov fixator removal.

All the patients with minor complications were among the patients where lengthening or transport was done; this also caused distal joint stiffness.

3. External fixation index- (EFI)

There were 16 patients who had distraction osteogenesis. They were grouped as –

1. With the EFI less than 60days/cm and
2. With the EFI more than 60 days/cm.

The range was 33-100 days/cm (69days/cm or 2.3m/cm). 9 out of 16 (56%) had an EFI of more than 60d/cm. Of these 9, 8were from a far locality who did not come for regular follow up.

Table 2 -Factors affecting EFI

Factors affecting EFI	EFI		Total No. of Pts
	< 60d/cm	>60d/cm	
Smoking	3(34%)	8 (66%)	11
Chronicity >6m	3(34%)	6 (66%)	9
Type of NU Gap/LLD	4(39%)	6 (61%)	10
Open fractures	5 (40%)	7 (60%)	12

As smoking was a factor that influenced the outcome, the EFI was compared between smokers and non smokers. EFI in smokers was 2.5months/cm where as in nonsmokers 1.75m/cm.

Considering the type of treatment- 5 out of 8 patients in only transport and 3 out of 8 patients in docking and lengthening had an EFI >60. From this we observed that the EFI was shorter in docking and lengthening group.

4 . Radiographic consolidation index-(RCI)

The patients were grouped as-

1. RCI less than 45days/cm and
2. RCI more than 45 days/cm. There were 9 patients in the earlier group and 7 in the later group. The range was 20-70days/cm(mean 45d/cm or 1.5m/cm).Two patients had a hypotrophic regenerate .

The factors observed to delay the RCI were -Non compliance of patient, violent corticotomy causing communition , chronicity and smoking.

Effect of smoking on RCI is shown in table 3.

Table 3- Effect of smoking on RCI

	Our study
RCI in smokers-	1.6 m/cm (48days/cm)
RCI in nonsmokers-	0.9 m/cm (28days/cm)

Effect of chronicity and smoking on RCI is shown on table 4.

Table 4 -Effect of chronicity and smoking on RCI

	RCI </=45	RCI >45	Total No. of Pts.
Chronicity >6m	3	6 (66%)	9
Smoking	4	7 (63%)	11

5. Bone results-

24 patients (62%) had excellent, 12(30%) had good and 3(8%) had poor results. As ASAMI protocol does not consider bone union obtained after bone grafting as excellent, one patient who had excellent result was considered to have a good result.

Out of the 3 who had poor results two had nonunion and one had refracture. Union was achieved in 37 of 39 patients. One had persistent infection, 4 had valgus deformity (8-25deg), one had 10 deg external rotation deformity and none had LLD more than 2.5cm. However the LLD ranged from 0.5-2cm (mean 1cm) was observed in 17 patients.

The bone results are shown in table 5.

Table 5- The bone results

	YES	NO
Union	37 (95%)	2
Infection	1	38
Deformity (16deg)	5 (4val,1ER)	34
LLD(>2.5cm)	None	39

The factors observed to affect the deformity are - Communition (3 out of 4 patients with communition had deformity), inadequate stabilization during transport (2 out of 4 had deformity), improper ring application (3 out of 4 had deformity).

6. Functional results-

7 patients (18%) had excellent, 29 patients (76%) had good and 2 patients (6%) had fair results.

The problems observed after functional assessment were-

- Noteworthy limp- 3 patients
- Joint stiffness- 1 had knee stiffness
  9 had ankle stiffness
  1 had equinus
- Soft tissue dystrophy- 7 pts had edema, adherent scar & scars of multiple surgeries.
- Pain- 2 had persistent pain.
- Inactivity- None.

The comparison with other studies is shown in table 6.

The statistical analysis for all the factors affecting the outcomes were analyzed using Chi square test and no factor was found statistically significant because of the limited number of patients.

Table 6- showing the comparision of the bone and functional results

Results	Our results 39 pts		Dendrinos et al 28 pts		Lalit et al 23 pts	
	Bone	Fn	Bone	Fn	Bone	Fn
Excellent	62%	18%	50%	25%	66.7%	26.7%
Good	30%	76%	28.5%	47%	13.3%	40%
Fair	None	4%	3.5%	14%	None	10%
Poor	8%	None	18%	14%	20%	23.3%

DISCUSSION

Infected nonunion is still an extremely difficult clinical problem despite major advances in the fixation technique, soft tissue management and antibiotic therapy. The infection of the fracture site not only prevents stable internal fixation but also delays fracture healing. The combination of mechanical instability and infection of a fractured bone provides an unfavorable condition for fracture healing. If the infection is not controlled, the fracture healing processes are eventually arrested.

Debridement is the most important step in the treatment of the infected elements. After debridement bony reconstruction can be done by different methods of bone grafting or by using the Ilizarov fixator.

This study describes the outcome of infected nonunions of the tibial shaft treated with an Ilizarov ring fixator. We have analyzed the outcome by studying the following factors.

1. Union time.
2. Complications.
3. External fixation index
4. Radiological consolidation index
5. Bone and functional results.

Union time: Union time is not the part of ASAMI protocol. We have studied the time to union and also analyzed the factors responsible for prolonging the healing time. The union time ranged 3–17months. The patient with union time of 3months had active drainage for more than 3months before becoming quiescent. He had hypertrophic non union with loss of 3cm of bone. After adequate stabilization the nonunion healed after 3months. Lengthening was done by distraction through a proximal corticotomy.

Union time for most patients ranged between 5-9months. The result was comparable to other results .The mean union time for infected fractures of tibia nonunion treated by the Ilizarov fixator was nearly 6months in the study by G.K. Dendrinos et al [39] in 1995 and Marsh et al [51] in 1997.

The patient with the longest union time of 17months had an interesting finding to note. There was an avascular bone fragment that prevented fracture site from aproximating . Other factors were the unstable fracture pattern which needed readjustment of the frame to prevent translation.

Two patients did not unite at final follow up. One (Case no.11) of them had sustained a polytrauma with a closed contralateral femur and acetabular fracture and head injury. Intra medullary nailing was done for left femur which united in 2months. After initial debridement and external fixator application, there was 3cm gap between the fracture ends. Once the Ilizarov fixator was applied he required corticotomies twice because of premature consolidation of the corticotomy and patient’s non-compliance. In view of this the non union site was bonegrafted. After about 5months of bone-grafting the Ilizarov fixator was removed because of persistant pin site infection and patient’s non compliance, even though the radiological union seen was a very sparse attempt at union. At the time of follow up it was noted that the patient had a hypertroptic non-union a hypertrophied fibula. Although his radiological outcome was poor, his functional outcome was good.

Another patient (Case no.17) had a non-union in the lower third tibia. He was from a distant region, chronicity of 4 years, with multiple previous surgeries and a segmental fracture. The proximal fracture had united. An active infection (MRSA), an Olive wire placed through the fracture site (Technical error) at the time of Ilizarov ring application and sclerosed bone ends (probably inadequate debridement) were observed to be the cause of the non-union.

Complications

The common complications were pin tract infection and transient edema which resolved by non-operative means. The pin track infections were treated by local injection with gentamycin and regular dressings. The major complications that affected the outcome were joint stiffness, refracture, reinfection and non-union.

The reasons for the true complications observed were –

1. Joint stiffness- Noncompliance of patients

   Initial injury

   Distraction osteogenesis

2. Reinfection- Poor soft tissue condition

   Persisting cavity

3. Refracture- Smoking, Co morbidity, Premature removal of ring,

   Ununited fibula fracture at the same level, Equinus deformity.

One patient (Case no.6) a smoker and hyperthyroidism who had an equinus contracture of 20 degrees, valgus deformity of 15 degrees, fell from a few steps and sustained type-IIIA open refracture 6months after Ilizarov frame removal. He was treated with Ilizarov ring fixator again because of the unfavorable soft tissue condition and the fracture united in 7 months.

Premature removal of the fixator and with-holding bone-grafting for a fracture with gap in anterior cortex was the reason for another refracture (case no. 33). The fracture united after intramedullary nailing.

In all the patients the infection was controlled except for one (Case no.7) who had recurrent pus discharge because of the persisting cavity within the bone. All the patients who underwent distraction osteogenesis had distal joint stiffness because the muscles respond poorly to the distraction rate of 1mm/day and as the gastrosoleus forms the main bulk in the calf, it resulted in ankle stiffness. The stiffness was overcome to some extent by regular physiotherapy and at follow-up patients with no dorsiflexion but a plantigrade foot had difficulty in squatting but could manage by modification of posture. Another cause of ankle stiffness was foot drop that resulted from initial injury to tendons (No.49). After regular physiotherapy he was able to have plantigrade foot.

The commonest complication in the literature has been pin related infection. Our results were comparable to other studies. In the study by Lalit Maini et al [48] on the Ilizarov method in infected nonunion of fractures, they noticed few true complications in 23 tibial fracture nonunions. Two sustained refractures, two had reinfection and thirteen had joint stiffness.

In the study by G.K Dendrinos et al [39] on 28 infected nonunions of tibia, three had nonunion, one had refracture, thirteen had joint stiffness and eleven had axial deviation as true major complications.

EFI

The mean EFI in our study was 69 days/ cm (2.3m/cm). The main reason for a longer EFI is that, 8 out of 9 patients were from distant regions and did not come for follow-up regularly. It was also longer in smokers which is attributed to the vasoconsrictive effect of nicotine that inhibits tissue differentiation and the angiogenic response necessary in the early stages of fracture healing. Furthermore, nicotine interferes with osteoblast function and alters skeletal metabolism. [49,50] Smoking affects both union time and the radiological consolidation index which inturn affect the EFI. In a study by Bobroff et al [41] for treatment of large defects in tibia, mean EFI was 2m/cm, but in smokers it was 2.6m/cm compared to non-smokers (1.45m/cm). Smoking is one of the modifiable factors which influence EFI, so every patient who is undergoing Ilizarov treatment for non-union has to be strongly advised to quit smoking.

Observed reasons for the increased EFI were –

1. Non compliance of patient
2. Smoking
3. Chronicity
4. Type of NU
5. Type of fracture

There are many reports that recommended decreasing the EFI by means of lengethening over an IM nail. In 2006 Mehmet Kocaoglu et al [42] studied 13 patients with segmental bone defect of femur and tibia associated with infection and these were treated by two stage surgeries, the first being radical debridement with antibiotic bead insertion and 6 weeks later (once ESR, CRP are negative) bone transport to fill the defect using intamedullary nail and an Ilizarov ring fixator. They concluded that this combined method reduced significantly the EFI and RCI .Mean EFI- 13.5days/cm and mean RCI- 31.7days/cm. Mean time to union was 9months (5-6m). Debridement level was determined by intravenous contrast enhanced MRI of whole long bone, which displays all necrotic tissues and skipped abscesses. The earlier removal of external fixator is associated with increased patient comfort, a decreased complication rate and a rapid rehabilitation.

The study done by Paley et al in 1997 [43] which compared use of only Ilizarov versus intramedullary nail and external fixator showed the same results as Mehmet et al but the cost and blood loss were higher in lengthening over IM nail.

However in a study by Kristiansen et al [44] for lengthening of tibia over an IM nail using Ilizarov fixator for constitutional shortness there were increased number of major complications (deep intramedullary infection) and slow consolidation (which they attributed to reduced endosteal blood supply after reaming and lack of soft tissue cover anteromedially for tibia as compared to femur). For these reasons they prefer the traditional callotasis lengthening technique.

We also observed that the EFI is shorter in patients in whom docking and lengthening was done, compared to only the transport group. The reason being earlier the fracture ends come in to contact, faster will be the union. In 1995 Saleh et al [46] compared the results of the treatment of bone defects by bone transport with those of acute limb shortening followed by lengthening. They obtained excellent results in 12 patients (75%) and good in 4 (25%). They found a shorter treatment time and fewer complications with limb shortening and relengthening . They recommended that acute shortening should be considered for tibial defects of less than or equal to 3cm and femoral defects of less than or equal to 5cm.

RCI

The mean RCI was 45days/cm which was comparable to other studies. Two had hypotrophic regenerate and were from distant regions. One patient (Case no.22) had a middle third non-union with bone loss for which bone transport of 7cm length was done. After the corticotomy the patient did not attend the out patient department regularly and continued the distraction unsupervised. He came back after 2months with a hypotrophic regenerate. This patient also had a deformity of the tibia because the transported segment was not properly stabilized.

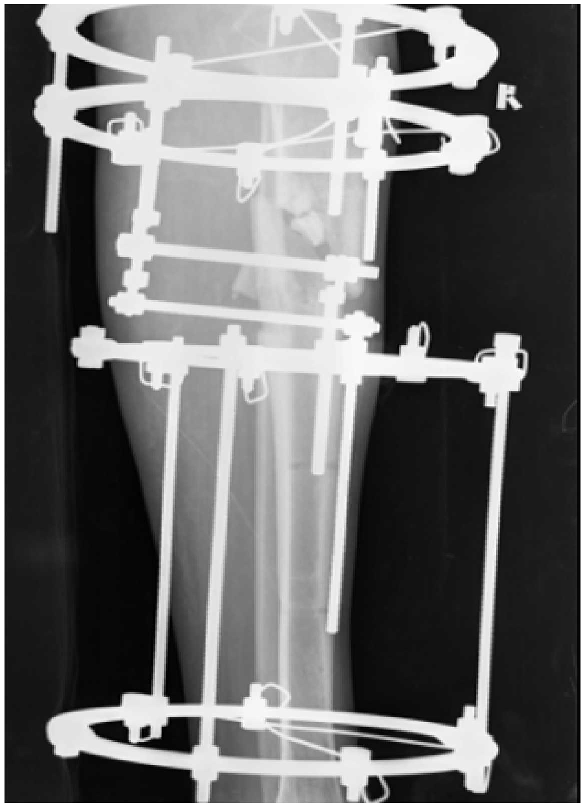
The other patient (case no.28) had distal third non-union with gap of 3cm. He had communition at the corticotomy site which resulted in hypotrophic regenerate. In smokers the vascularity of the tissues is reported to be poorer than in their nonsmoking counterpart hence we presume that the delay seen was a result of this poor perfusion.

Bone and functional results

Among the three who had poor results, two had non-union and one had refracture. The most common observed cause for deformity was the communition at the fracture site and improper application of the Ilizarov ring fixator. The accepted deformity according to to ASAMI protocol is 7^0 but one of patient had valgus deformity of 25^0 in the lower end which resulted in pain in the ankle region on ambulation. But as he was 74 year old he refused any further surgical intervention and could manage his daily activities.

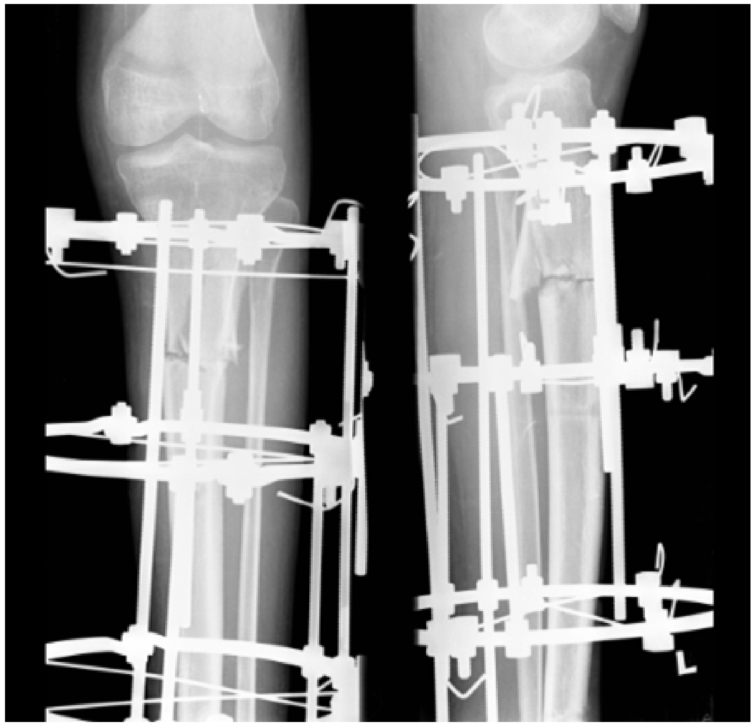
The soft tissue dystrophy was considered to be poor (according to Paley D) if the patient has decubitus ulcers or hyperaesthesia of the limb. Only 2 of our patient had presistent pain over the affected leg. 7 patients had unfavourable soft tissue condition with persistent edema, adherent scar and multiple surgical scars. Our bone and functional results were observed to fair better than the other results (as shown in the table 6).

Avascular bone fragment preventing union

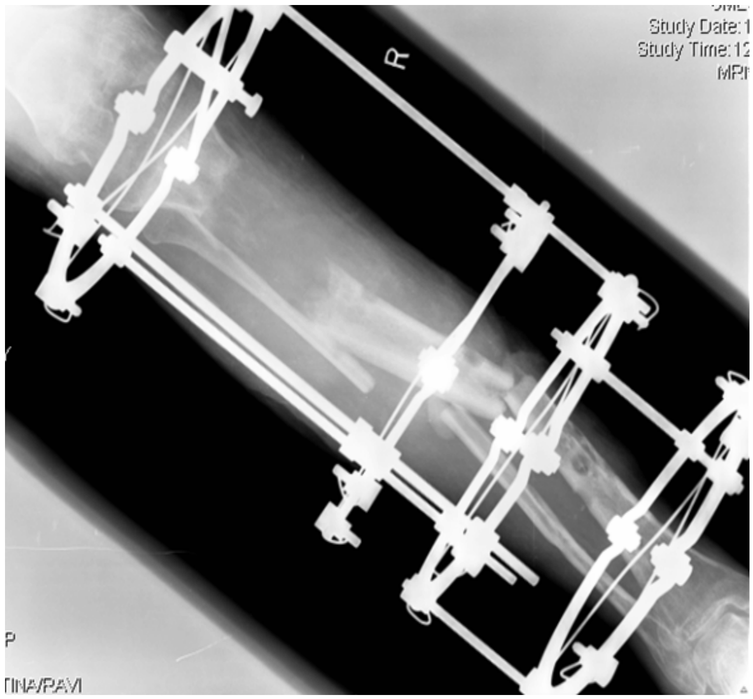


Olive wire placed in the fracture site

Communition at corticotomy resulting in hypotrophic regenerate



Hypotrohic regenerate resulting from unsupervised distraction-



Persisting cavity within the bone causing reinfection-

Ring sequestrum-

Refracture –Case no 6

Refracture – Case no 33

Axial deformity- valgus of 25 degree.

Excellent radiological outcome in the patient who had 10cm bone transport - normal regenerate, good alignment and good union.

Good functional result in the patient who had 10cm bone transport .

Good functional result in a patient with nonunion tibia and hypertrophic fibula

Good functional result in a patient with nonunion tibia and hypertrophic fibula-

Nonunion of tibia with hypertrophic fibula-

Fair functional result- Local edema, multiple surgical scars and limb length discrepancy

CONCLUSIONS

1. With the Ilizarov fixator an excellent union rate of 95% and favorable functional result of 94% was achieved in infected nonunions of tbia.
2. Union time averaged 9.5months and was influenced by communition, active infection, type of nonunion, type of fracture and smoking.
3. In patients who underwent bone transport, External fixation index was 2.3m/cm and Radilogical consolidation index was 1.5m/cm which were comparable to other studies.
4. External fixation index and Radilogical consolidation index was increased in smokers.
5. The factors observed to cause nonunion at the end of treatment were
   a. Unstable fracture configuration.
   b. Technical error.
   c. Avascular cortical bone between fracture ends.
   d. Inadequate debridement.
   e. Smoking
6. Compliance of the patient is a major factor in getting good results in lengthening procedures.

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MASTER CHART

TABLE 1-

Smoking – 1- yes; 2- no.
Sinus - 1- yes; 2-no.
Infection- 1- Quiescent; 2- Active
Antibiotic sensitivity- 0- no growth, 1- sensitive to first line,2- resistant to first line (MRSA).
Associated injury- 1- yes; 2-no.

TABLE 2-

Frame construct- 1- 3 ring; 2- 4 ring; 3- 5ring; 4- 4 with foot ring.
Consolidation- 0- No distraction; 1- normal; 2- hypotrophic; 3- hypertrophic
Problem- 1- Axial deviation, transient pain, transient edema
2- Transient pain, transient edema
Obstacle- 1- pin tract infection

TABLE 3-

Union – 1- yes ; 2- no
Infection- 1- present; 2- eradicated
Deformity- 2- no or less than 7 deg
LLD(limb length descrepency >2.5cm) – 1-yes; 2- no
Bone result – 1-excellent; 2- good; 3- fair; 4- poor
Limp- 1- noticeable, 2- not noticeable
Soft tissue dystrophy (STD)- 1- yes; 2-no.
Pain- 1- present; 2- absent.
Inactivity - 1- inactive; 2- active
Functional results- 1-excellent; 2- good; 3- fair; 4- poor

TABLE -1

Pt's S.No	AGE/SEX	Smoking	Comorbidity	DIAGNOSIS	FRACTURE	SINUS
1	46y/M	1	Asthmatic	INU,D/3,Lt	Open 3B	1
2	35y/M	2	NIL	INU,M/3,Rt	Open 3B	1
3	55y/M	2	DM	INU,M/3,Rt	Open 3B	1
4	38y/M	1	NIL	INU,P/3,Rt	Open 3B	2
5	30y/M	2	NIL	INU,Segmental,Rt	Open 3B	1
6	38y/M	1	Hyperthyroid	INU,M/3,Rt	Open 3B	1
7	46y/M	2	NIL	INU,D/3,Lt	Open 3B	1
8	43y/M	2	DM	INU,M/3,segmental,Rt	Open 3A	2
9	27y/M	2	NIL	INU,D/3,Rt	Open 3A	2
10	41y/M	2	DM	INU,M/3,Lt,Implant in situ	Closed	1
11	31y/M	2	NIL	INU,Segmental,M/3,Rt	Open 3B	2
12	32y/M	1	DM	INU,D/3,Lt,with implant in situ	Open 3A	1
13	51y/M	1	DM	INU,M/3,Rt	Open 3B	1
14	22y/M	1	NIL	INU,M/3,Lt	Open 3B	1
15	44y/M	1	NIL	INU,D/3,Rt	Open 3B	2
16	55y/M	1	NIL	INU,M/3,Lt with imlant in situ	Closed	1
17	30y/M	1	DM	INU,D/3,Lt with foot drop	Open 3B	1
18	43y/M	1	NIL	INU,M/3,segmental,Lt	Open 3B	1
19	53y/M	2	NIL	INU,M/3,communitted,Lt	Open 3B	1
20	49y/M	2	NIL	INU,L/3,Lt with recovering CPN palsy	Open 3B	1
21	25y/M	2	NIL	INU,L/3,Lt	Closed	2
22	35y/M	1	NIL	INU,M/3,communitted,LRt	Open 3B	1
23	43y/M	2	NIL	INU,D/3,Rt	Open 3B	2
24	35y/M	1	DM	INU,M/3,Rt	Open 3B	1
25	37y/M	2	NIL	INU,M/3,Rt	Open 3A	2
26	28y/M	1	NIL	INU,D/3,Rt	Open 3B	2
27	25y/M	1	NIL	INU,M/3,Lt	Closed	2
28	34y/M	2	NIL	INU,D/3,Lt	Open 3B	1
29	31y/M	1	Hypertension	INU,M/3,Rt,with gap	Open 3B	1
30	50y/M	1	NIL	INU,D/3,Lt	Open 3B	1
31	74y/M	2	Hypertension	INU,L/3,Rt,segmental	Open 3B	2
32	37y/M	1	NIL	INU,D/3,Rt,nail in situ	Closed	2
33	46y/M	2	NIL	INU,M/3-D/3,Rt	Open 3B	2
34	25y/M	2	NIL	INU,L/3,Rt	Open 3B	2
35	40y/M	1	NIL	INU,M/3,Rt,segmental	Open 3A	1
36	28y/M	2	NIL	INU,L/3,Rt with imlant in situ	Open 3B	2
37	36y/M	2	NIL	INU,D/3,Rt	Open 3B	1
38	26y/M	2	NIL	INU,D/3,Rt,with gap ,on exfix	Open 3B	1
39	58y/M	1	DM,HTN,IHD	INU,D/3,Lt with implant in situ	Open 3A	1

TABLE - 1

Pt's S.No	Shortening	ROM-KNEE	ANKLE-DF	ANKLE-PF	ST CONDN.	DEF(Deg)	Infn.	INF. ORGANISM
1	4 cm	140	5	5	Fair	Val-14	2	E.coli,Klebsiella
2	0	100	10	10	Fair	0	2	Staph.aur
3	0	5	5	5	Fair	Val-12	2	No growth
4	5cm	5	10	20	Fair	0	1	No growth
5	0	90	20	30	Fair	Val-15deg	2	No growth
6	3cm	140	20	30	Fair	0	1	No growth
7	0	90	0	30	Poor	0	2	E.coli,Enterococcus,Proteus
8	0	80	20	30	Fair	0	1	No growth
9	0	140	20	30	Fair	Val-7	1	No growth
10	1cm	100	20	30	Fair	Var-6	2	MRSA
11	1.5cm	130	20	30	Fair	0	1	No growth
12	0	140	10	20	Fair	0	2	Ps.aeruginosa
13	0	140	10	30	Poor	0	2	Pr.mirabilis; Staph.aur
14	0	80	15	20	Fair	Val-10deg	2	Staph.aur
15	4cm	140	10	20	Fair	Varus-6d	2	No growth
16	0	90	20	30	Poor	0	2	No growth
17	1cm	120	10	20	Fair	Varus-12d	1	Staph.aur
18	0	140	10	30	Fair	0	1	No growth
19	1cm-S	140		30Eq	Poor	0	1	GNB,Proteus vulgaris
20	0	130	10		Fair	0	2	Klebsiella,Enterobacter
21	1cm-I	90	10	20	Fair	0	1	Staph.aur
22	0	10-120	0		Fair		2	Staph.aur
23	0	140	0	30	Fair	0	1	No growth
24	1cm	45-110	0		Poor	0	2	Staph.aureus
25	0	140	15	10	Fair	0	1	No growth
26	0	130	20	30	Poor	0	1	No growth
27	1cm	90	10	10	Fair	Varus 12d	1	No growth
28	0	120	10	20	Poor	0	2	Staph.aureus
29	3cm-S	60	0		Fair	0	2	No growth
30	1.5cm-S	60	10	20	Poor	0	2	Staph.aureus
31	1cm-S	70	0	10	Poor	0	1	No growth
32	0	100	10		Fair	0	1	No growth
33	0	140	20	30	Fair	0	1	No growth
34	0	90	10	20	Fair	AP-10	1	Ps.aeruginosa
35	0	10(FFD)	10	20	Fair	Crooked	1	No growth
36	0	140		10d-20d	Fair	varus 13d	1	No growth
37	2cm-I	140	10		Poor	0	2	E.coli, Ps.aeruginosa,Proteus
38	1.5cm-S	90	10	20	Fair	0	2	Staph.aureus
39	1.5cm	10d-45deg		10 deg Eq	Fair	0	2	Streptococcus

TABLE - 1

Pt's S.No	Ab SENS	No OF PREV. Sx	ASSOC. INJ	TYPE OF NU
1	1	2	1	B2
2	2	1	1	A1
3	0	1	2	A1
4	0	1	2	B3
5	0	0	2	A1
6	0	1	2	B3
7	1	2	2	A1
8	0	2	1	A1
9	0	1	2	A1
10	2	1	1	A1
11	0	1	1	B3
12	1	1	1	A1
13	2	1	2	B1
14	2	1	1	A1
15	0	2	2	B2
16	0	1	1	A1
17	2	3	1	A1
18	0	1	2	A1
19	2	2	2	A1
20	1	1	1	A1
21	2	2	2	B2
22	2	2	2	A1
23	0	2	2	A2.1
24	2	1	1	A1
25	0	1	2	A1
26	0	2	2	A1
27	0	2	2	A2.2
28	2	1	2	A1
29	0	1	2	B3
30	2	1	2	B3
31	0	2	2	A1
32	0	3	1	A2.2
33	0	1	2	A1
34	1	1	1	A1
35		1	2	A1
36	0	2	1	A2.2
37	1	2	1	B2
38	2	3	1	B3
39	1	1	2	B2

TABLE - 2

Pt's S No	Sx DATE	No OF Sx	Sx DONE	FRAME	Consolidation
1	04/03/2005	1	Deb,Ilz & corticotomy	3	1
2	02/02/2005	3(2 Readj)	Deb,Ilz	2	0
3	10/03/2000	1	Deb,Ilz	1	0
4	04/10/2000	1	Deb,Ilz & corticotomy	2	1
5	08/07/2000	1	Deb,Ilz	1	0
6	22/03/2002	2(1 added 1ring)	Ilizarov, corticotomy	2	1
7	01/04/2005	1	Deb,Ilz	2	0
8	06/06/2003	1	Ilizarov	2	0
9	01/12/2001	1	Ilizarov	2	0
10	23/05/2001	1	IE,Deb,Ilizarov,corticotomy	2	1
11	01/02/2002	3(2corticotomies,1BG)	Ilizarov, corticotomy	2	0
12	16/10/2000	1	IE,Deb,Ilizarov	2	0
13	13/06/2003	1	IE,Deb,Ilizarov,corticotomy	2	1
14	20/11/2002	1	Deb,Ilz	2	0
15	03/04/2001	3(2 corticotomies)	Deb,Ilz & corticotomy	1	1
16	11/07/2003	3(corticotomy,Z-plasty)	IE,Deb,Ilizarov,corticotomy	2	1
17	19/03/2004	1	IE,Deb,Ilizarov	2	0
18	26/02/2003	1	Deb,Ilz	2	0
19	17/03/2004	2(sequestrectomy & BG)	IE,Deb,Ilizarov	2	0
20	27/05/2005	3(BMI, BG)	Deb,Ilz	1	0
21	19/04/2002	1	Deb,Ilz & corticotomy	2	1
22	21/08/2002	2(corticotomy)	IE,Deb,Ilizarov,corticotomy	2	2
23	05/12/2003	1	Ilizarov	1	0
24	10/08/2000	1	Deb,Ilz & corticotomy	2	1
25	14/11/2003	1	Ilizarov	2	0
26	07/04/2004	1	Deb,Ilz	2	0
27	08/05/2002	1	Deb,Ilz & corticotomy	2	1
28	05/09/2003	2(sequestrectomy &local flap)	Deb,Ilz & corticotomy	4	2
29	07/12/2001	2(recorticotomy)	Deb,Ilz & corticotomy	2	1
30	03/02/2000	3(Iz,BG,BMI,TA length)	Deb,Ilz & corticotomy	1	1
31	09/01/2004	1	Ilizarov	2	0
32	15/09/2006	1	Ilizarov	3	0
33	21/11/2003	1	Ilizarov	2	0
34	08/08/2003	1	Deb,Ilz	2	0
35	07/04/2000	1	Deb,Ilz	2	0
36	06/09/2002	2(Re ilizarov)	Deb,Ilz	2	0
37	05/04/2005	1	Deb,Ilz & corticotomy	2	1
38	12/04/2002	1	Deb,Ilz & corticotomy	2	1
39	17/01/2001	1	Deb,Ilz	2	0

TABLE - 2

Pt's S No	UNION TIME	TYPE OF TREATMENT	Total duratn.	F/U
1	6m	Bifocal (grad docking & lengthening)	15m	36m
2	17m	Unifocal	19m	36m
3	9m	Unifocal	12m	99m
4	8m	Bifocal(only lengthening)	12m	84m
5	16m	Bifocal(segmental)	16m	48m
6	7m	Bifocal(only transport)	19m	60m
7	5m	Unifocal	11m	32m
8	8m	Unifocal	12m	48m
9	5m	Unifocal	7m	72m
10	5m	Bifocal(only lengthening)	10m	72m
11	**Nonunion**	Unifocal	10m	72m
12	6m	Unifocal	12m	84m
13	6m	Bifocal(only transport)	14m	50m
14	7m	Unifocal	16m	64m
15	2m	Bifocal(only lengthening)	14m	65m
16	5m	Bifocal(grad dock & lengthening)	16m	64m
17	8m	Unifocal	9m	50m
18	9m	Unifocal	12m	68m
19	6m	Unifocal	12m	55m
20	12m	Unifocal	15m	36m
21	6m	Bifocal(only transport)	11m	72m
22	12m	Bifocal(only transport)	18m	48m
23	5m	Unifocal	9m	60m
24	6m	Bifocal (only transport)	24m	72m
25	4m	Unifocal	8m	60m
26	6m	Unifocal	8m	54m
27	3m	Bifocal(ac. Dock & lengthening)	5m	72m
28	6m	Bifocal(grad dock & lengthening)	14m	60m
29	6m	Bifocal(grad dock & lengthening)	14m	84m
30	8m	Bifocal(only transport)	20m	96m
31	7m	Bifocal(segmental)	16m	55m
32	6m	Unifocal	12m	36m
33	5m	Unifocal	14m	62m
34	5m	Unifocal	14m	60m
35	10m	Bifocal(segmental)	12m	72m
36	6m	Unifocal	21m	72m
37	10m	Bifocal (only transport)	12m	42m
38	8m	Bifocal(only transport)	20m	72m
39	11m	Unifocal	12m	16m

TYPE - 2

Pt's S No	Prob	Obst	True complcn	
1	1			0
2	1	1		0
3	1	1	joint stiffness	
4	2	1		0
5	1	1		0
6	1	1	joint stiffness & refracture	
7	2	1	reinfection	
8	2	1		0
9	2			0
10	2	1		0
11	2	1	nonunion	
12		1		0
13	2	1		0
14	2	1		0
15	2	1		0
16	2	1		0
17	1	1	nonunion	
18	1	1		0
19		1		0
20		1		0
21	2	1		0
22	1	1		0
23		1		0
24	2	1		0
25	1	1		0
26	1	1		0
27	2	1		0
28	1	1		0
29	2	1		0
30	2	1		0
31	1	1		0
32	2	1		0
33	2	1	refracture	
34	2	1		0
35	1	1		0
36	1	1		0
37	2	1	joint stiffness	
38	2	1		0
39	2	1		0

TABLE - 3

Pt's S No	EFI(d/cm)	RCI(d/cm)	Union(m)	Infn	DEF(>7Deg)	LLD(>2.5cm)	BONE RES
1	75	50	1	2	2	2	2
2			1	2	2	2	1
3			1	2	9deg valgus	2	2
4	76	60	1	2	2	2	1
5			1	2	15deg val	2	2
6	90	50	1	2	2	2	1
7			1	1	2	2	2
8			1	2	2	2	1
9			1	2	2	2	1
10	60	45	1	2	2	2	1
11			**2**	2	2	2	**4**
12			1	2	2	2	1
13	75	45	1	2	10deg ext rotn	2	2
14			1	2	2	2	1
15	60	45	1	2	2	2	1
16	50	22	1	2	2	2	1
17			1	2	2	2	4
18			1	2	2	2	2
19			1	1	2	2	2
20			1	1	2	2	1
21	70	20	1	2	2	2	1
22	100	56	1	2	8deg val	2	2
23			1	2	2	2	1
24	60	45	1	2	2	2	2
25			1	2	2	2	1
26			1	2	2	2	1
27	75	53	1	2	2	2	1
28	90	70	1	2	2	2	2
29	60	40	1	2	2	2	1
30	100	60	1	2	2	2	1
31			1	2	25deg val	2	2
32			1	2	2	2	1
33			2	2	2	2	4
34			1	2	2	2	1
35			1	2	2	2	1
36			1	2	2	2	1
37	40	25	1	2	2	2	1
38	33	25	1	2	2	2	1
39			1	2	2	2	1

TABLE -3

Pt's S No	Limp	ROM-KNEE	ANKLE-DF	ANKLE-PF	STD	Pain	Inactivity	Fn. RES
1	1	90	5	30	2	2	2	2
2	2	140	15	30	2	2	2	1
3	2	10 -15deg	0	10	1	2	2	2
4	2	90	30	30	2	2	2	1
5	2	140	0	30	2	2	2	2
6	1	100				2	2	3
7	2	120	15	15	1	2	2	2
8	2	80	20	30	2	2	2	2
9	2	140	20	30	2	2	2	1
10	2	130	20	30	2	2	2	1
11	2	130	20	30	1	2	2	2
12	2	140	10	15	2	2	2	2
13	2	140	20	30	1	2	2	2
14	2	140	30	30	2	2	2	1
15	2	140	10	30	1	2	2	2
16	2	140	5	5	1	2	2	2
17	2	130	10	15	1	1	2	3
18	2	140	20	30	2	2	2	1
19	2	140	0	30	1	2	2	2
20	2	130	0	25	2	2	2	2
21	2	125	0	5	2	2	2	2
22	2	130	0	15	1	2	2	2
23	2	130	10	30	1	2	2	2
24	1	130	0	20	1	2	2	2
25	2	140	20	30	2	2	2	1
26	2	140	20	30	1	2	2	2
27	2	140	10	30	2	2	2	2
28	2	140	0	30	1	2	2	2
29	2	130	0	30	1	2	2	2
30	2	130	0	20	1	2	2	2
31	2	140	20	20	1	2	2	2
32	2	130	0	20	1	2	2	2
33	2	140	10	10	1	2	2	2
34	2	120	10	20	2	2	2	2
35	2	90	10	20	1	2	2	2
36	2	130	10	20	1	2	2	2
37	2	140	0	10	1	1	2	3
38	2	140	15	20	1	2	2	2
39	2	90	0	20	1	2	2	2